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Introduction: The airborne dust is omnipresent in the Martian atmosphere. It can be taken into account in a straightforward way, while modeling the spectral radiances of TES. These radiances are obtained from the numerical solution of the corresponding forward RT problem (RT equation and boundary conditions). But retrievals of atmospheric and surface parameters require knowledge of sensitivities (weighting functions and/or partial derivatives) of measured radiances to the parameters to be retrieved. This circumstance creates the problem. Closed-form expressions of these sensitivities through atmospheric/surface parameters exist only in the case when there is no atmospheric scattering, and the solution of the RT equation can be obtained analytically.

It turns out that the solution of the corresponding *adjoint* RT problem provides a way to compute the required sensitivities with an accuracy comparable with that of radiances obtained from the solution of the forward RT problem. The adjoint solution can be obtained in parallel with the forward solution, incurring only moderate increase of computer time required, as compared to obtaining of the forward solution. Modeling of radiances and evaluation of sensitivities is conveniently combined in a single forward/adjoint RT algorithm. The computer time required is still substantially greater as compared to evaluation of sensitivities with no-scattering assumption. This is why our effort is limited to the subset of TES data. Our goal is to provide the reference retrievals using a subset of data already processed with the TES team and to demonstrate retrievals of atmospheric and surface parameters not hindered by the no-scattering assumption.

Principles of the adjoint approach to sensitivity analysis: In this Section we will use the generalized (but not symbolic) notations. The observed radiances R can be considered as a convolution of the total field of radiation I with the instrument's function W which defines spectral, angular (and, implicitly, spatial) resolution:

$$R = (W, I) \qquad (1)$$

The total field of radiation I is obtained as a solution of the forward RT problem which can be combined [1] into a single linear operator equation featuring the source function of radiation S and the linear RT operator L:

$$LI = S \qquad (2)$$

Thus, the observables R are defined by the triad L, S, and W.

Adjoint RT problem provides an alternative way to use the triad L, S, and W to compute the observables R. More importantly, it provides a way to directly relate the variation of any atmospheric/surface parameter δX to the corresponding variation of observables δR [2]. This, in turn provides an analytic way to compute sensitivities of R to X: weighting functions, if X depends on altitude, like atmospheric temperature, or partial derivatives, if X is a scalar parameter, like surface temperature.

The key feature of the adjoint RT problem is the adjoint RT operator L^*. It is uniquely derived from the RT operator L [1] using the definition

$$(g, Lf) = (L^* g, f) \qquad (3)$$

Then, the alternative way to compute the observables R from the triad L, S, and W is given by the convolution

$$R = (I^*, S) \qquad (4)$$

of the source function S with the solution I^*, of the adjoint RT problem

$$L^* I^* = W \qquad (5)$$

The variation of observables δR is directly expressed [2] through variations of δL and δS:

$$\delta R = (I^*, \delta S - \delta L I) \qquad (6)$$

Expression (6) provides a basis of the applications of the adjoint approach to computations of sensitivities of observables to any atmospheric/surface parameters in remote sensing. The equation and boundary conditions of the adjoint RT problem (5) are very similar to those of the forward RT problem (1), and the same numerical method can be used to obtain the numerical solutions I and I^*. Thus, a single pair of these solutions obtained for a given atmospheric/surface model can be used for computations of the spectra and their sensitivities to all the parameters of interest.

It should be pointed out that the capability to compute all weighing functions and/or partial derivatives of interest does not, of course, mean that all the parameters of interest can be retrieved simultaneously from a single spectrum. It is the information content of data, which define the extent of information on atmospheric and surface parameters which can be retrieved, not the method to compute the sensitivites..

Applications to TES data: The work to be done can be grossly divided into the following categories:

1) Sensitivity analysis of TES spectra using available atmospheric/surface models;
2) Retrievals of single parameters (e.g., atmospheric temperature) with other parameters kept constant;
3) Simultaneous retrievals where warranted by an information content of available data.

While our team is composed of atmospheric specialists, an important goal of our project is the retrieval of surface protperties, most importantly, the surface emissivity and temperature.

The general strategy we are going to pursue is to perform retrievals from the data sets already processed using operational methods by TES team. The crucial assumption on which these methods are based is that there is no scattering in the Martian atmosphere. Since our approach can accurately treat atmospheric scattering, we believe that the most important input we can provide to the research community is to explore the ramifications imposed by this assumption.

Retrievals of atmospheric parameters. Atmospheric temperature is the first and most important atmospheric parameter in our retrieval list. Expressions for the temperature weighing functions are documented in [1] and the follow-up paper [3]. In the non-scattering case they converge to the corresponding expression for the blackbody atmosphere. We anticipate the method will be able study directly the influence of scattering of atmospheric dust on the accuracy of simplified retrievals. The temperature structure of the Martian atmosphere during a dust storm is also of significant interest in understanding their behavior and evolution. With our retrieval method, we also hope to be able to understand the changes in the temperature (and thus dynamics) of the atmosphere during a dust storm.

The dust loading in the Martian atmosphere is another important parameter. Again, lifting of the assumption on absence of scattering may alter existing estimates obtained from TES data. Although, there exists in principle the possibility of directly assessing the vertical distribution of dust from data in the wings of the 15 mcm band of CO2, in most cases we will be retrieving the total optical dust using different assumption on its vertical structure, e.g., homogeneous mixing with gaseous atmosphere.

Retrievals of surface parameters: Atmospheric correction or simultaneous retrievals? The ability to directly compute sensitifities of TES data to any parameter of interest makes it possible to reduce additional assumptions strictly to the limit required by the information content of data available in each particular case. Ideally, it would be desirable to perform simultaneous retrievals of the surface parameters (emissivity) and atmospheric parameters (temperature and dust loading). Allowing for the atmospheric scattering adds the single scattering albedo and whole phase function of atmospheric scattering to the suite of model parameters which, ideally, have to be retrieved simultaneously with the surface parameters. In practice, we will follow, to some extent, the concept of atmospheric correction, assuming, at least some atmospheric parameters to be known and retrieving the surface parameters. In all cases, we will allow for inclusion of atmospheric scattering and will explore how this effect affects the retrieved values.

Conclusion: The highly successful TES experiment onboard of *Mars Global Surveyor* provided a great wealth of excellent data during a period which now extends beyond one Martian year. We are excited with an opportunity to apply an alternative approach to the interpretation of these data and to contribute to the better understanding of the environment on Mars.

References:

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